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Research Article
Relationships between Primary and Secondary Yield Components of a Maize Population after 13 Stratified Mass Selection Cycles

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Abstract
This research aimed to identify the relationships between the primary and secondary components of the maize yield using the techniques of canonical correlation and factors analysis. The base population was composed of nine randomized crossing hybrids in an isolated field, in the years 2006-2012. Canonical correlations were estimated between the variable group consisting of primary (GI) and secondary (GII) yield components. To Factor Analysis (FA), we chose a number of common factors equal to the number of eigen values higher than the existing unit in the phenotypic correlations matrix of variables and the orthogonal factor model was opted. Primary and secondary yield components of maize grains are not independent. Inter-group associations are established by plants with higher height, stem diameter, dry weight and lower ear height, which positively influence primary yield components (dry ear weight, ear length and hundred-grain weight). Factor analysis allowed to reduce a large number of original variables observed to a small number of abstract variables and can be used to complement the canonical variables technique.

Key words: Factor analysis, canonical correlations, indirect selection, *Zea mays*, inflorescence length, chlorophyll content, stem diameter

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Maize (*Zea mays* L.) is one of the main cereals produced in the world, with a production of 981 million tons of grain in 2014 (FAO., 2015). Brazilian maize production of in the 2013/14 reached a volume of 79.9 million tons, of which about 48 million tons were produced in the second season with average grain yield of 5.255 kg ha^{-1} (Conab, 2015). Total area under maize in the country is 15.8 million hectares. For the State of Mato Grosso do Sul the production in the harvest 2013/14 was around 8.0 million tons with planted area of approximately 1.5 million hectares, which characterized it as the third major national producer (Conab, 2015).

However, Brazilian yield is still considered low given the productive potential of this crop. The selection of superior genotypes is intended to simultaneously identify multiple characters according to the requirements of a modern and competitive agriculture (Coimbra *et al*., 2000). In this sense, to know the correlations between the components of grain yield is important for plant breeding, since when the selection is based on a trait, other important agronomic traits are altered by being correlated to each other (Santos and Vencovsky, 1986).

Canonical correlation technique may be more appropriate to estimate the relationships between two groups of agronomic traits. Hair *et al.* (2006) emphasizes that this analysis consists of obtaining canonical functions, where each function is composed of one pair of statistical variables, representing the dependent and independent variables. The maximum number of canonical functions that can be obtained is equal to the number of the lowest set variable data. These authors also claim that the first pair of canonical statistical variables is obtained in order to have the greatest possible intercorrelation with variable groups. The second pair is also obtained to show the highest relationship between the analyzed variable groups, but that was not explained by the first pair and then successively.

In plant breeding, the simultaneous selection of several traits, when exerted on a few factors that represent various strongly correlated original traits may become more efficient (Granate *et al*., 2001). The factor analysis is a multivariate technique that reduces a high number of original variables to a small number of abstract variables also known as factors. Each factor will group a trait set, highly correlated to each other and weakly correlated to the traits, grouped in the other factors.

These techniques are being used to reveal membership in crops such as pigeonpea (Santos *et al*., 1994), pepper (Tavares *et al*., 1999), common bean (Coimbra *et al*., 2000), pumpkin (Neto *et al*., 2006), sugarcane (Da Silva *et al*., 2007), potato (Rigao *et al*., 2009) and wheat (Erayman *et al.,* 2006; Carvalho *et al*., 2015). Given the above, this work aimed to identify the relationships between the primary and secondary components of the maize yield using the techniques of canonical correlation and factors analysis.

MATERIALS AND METHODS

The trial was conducted at experimental area of Embrapa Agropecuária Oeste, municipality of Dourados, MS, Brazil (22°13'S and 54°48'W, at 400 m of altitude), in 2006-2012, in no-tillage system. The soil of the area is classified as oxisol of clay texture and the climate of the region according to Köppen classification is Cwa with hot summers and drougth winters. Maximum temperatures are observed in the months of December and January and minimum temperatures between May and August, coinciding with exceeding rain in the spring-summer and drought in autumn-winter (Fietz and Fisch, 2008).

The base population (Guepa-I) was composed of nine randomized crossing hybrids (Table 1) in an isolated field, where intermediate lines of each hybrid were sown in order to allow recombination among all genotypes and providing a population with a wide genetic basis were seeded. After the

Table 1: Cycle, grain color, grain texture, level of technology and the company holding of the hybrids used for forming the base population

Hybrids	Type	Cycle	Grain color	Grain texture	Level of technology	Company
AG9010	SH	SE	OR	HARD	H	Agroceres
BRS 1030	SH	E	OR	SMHARD	M/H	Embrapa
AGN 2012	DH	SE	AM	SMHARD	L/M	Agromen
AS 1548	SHm	SE	AV	SMHARD	M/H	Agroeste
BRS 1010	SH	E	OR/RE	SMHARD	M/H	Embrapa
AGN 34 A 11	TH	SE	OR	HARD	M/H	Agromen
XB 8010	DH	E	OR	HARD	M/H and L/M	Semeali
FORT	SH	E	OR	HARD	H	Syngenta
XB 7253	TH	E	OR	HARD	M/H and H	Semeali[1]

SH: Single cross hybrid, SHm: Modified single cross hybrid, DH: Double cross hybrid, TH: Triple cross hybrid, E: Early, SE: Super Early, OR, Orange, RE: Reddish, SMHARD: Semi-hard, H: High, M: Medium, L: Low formation of the base population, we proceeded with 13 stratified mass selection cycles.

In this case, the area of the selection field was composed of 2,250 m^2 (100 m×22.5 m), spaced 0.9 m between rows, where were established in four strata of 25 m in length, totaling 100 strata.

Each strata consisted of 100 plants, where it was used a selection intensity of 5% leading to selection of five plants per strata.

The selection was done separately for each strata based on the expression of the traits plant height, ear height, inflorescence length, chlorophyll, plant dry weight, stem diameter and disease resistance, being selected 500 plants, which were obtained 500 ears. In the post-harvest phase, the best ears were selected based on the ear length, dry ear weight, ear diameter, hundred-grain weight and grain yield, degree of thatch, type and grain color and, from the same plants were obtained the seeds of the first selection cycle.

Canonical correlations were estimated between the variable groups consisting of primary traits: Dry Ear Weight (DEW), Ear Length (EL), Ear Diameter (ED), Hundred Grain Weight (HGW) and Grain Yield (YIE). The second group was composed by secondary traits: Stem Diameter (SD), Ear Height (EH), Plant Height (PH), Inflorescence Length (IL), Dry Plant Weight (DPW), Chlorophyll Content (CC) and Plant Weight (PW), following the procedures described in Cruz and Regazzi (1997). The significance of the null hypothesis in which all the possible canonical correlations are null was assessed using the chi-square test.

For the Factor Analysis (FA), we chose a number of common factors, equal to the number of eigenvalues higher than the units existing in the matrix of the variable phenotypic correlations and the orthogonal factor model was adopted. After the initial calculation of factorial loads, the factors were submitted to a maximum of 50 rotations by the Varimax method for obtaining the final factorial loads (Cruz and Regazzi, 1997). All analyzes were performed using the SAS (1999) statistical software.

RESULTS AND DISCUSSION

Observing canonical correlations and its canonical pairs, we found that the first three groups were significant ($p \le 0.05$) using the chi-square test. This shows that the variables are not independent of each other, so that the variables related to morpho physiological traits defined in the group II indicates strong correlations with the variables related to grain yield of group I.

Consequently, the first three canonical variable pairs are of study interest, because these canonical variable pairs maximize the relationship between the primary components of the grain yield with the main morphological traits of the maize (Table 2). Correlation coefficients for the first three canonical pairs were 0.799, 0.680 and 0.381, respectively. Results of similar magnitude were observed in crops such as pigeonpea (Santos *et al.*, 1994), pepper (Tavares *et al.*, 1999), common bean (Coimbra *et al.*, 2000), pumpkin (Neto *et al.*,

Table 2: Canonical correlations and canonical pairs between primary components of the group I and secondary components of the group II, evaluated in the population Guepa-I, after 13 stratified mass selection cycles

	Canonical pairs				
Components	1°	2°	3°	4°	5°
Primary					
DEW	0.4082	1.4872	1.7291	0.6787	1.5464
EL	0.4902	0.7598	-1.8190	-0.4940	-1.0253
ED	0.2191	0.9111	-0.3848	-0.2186	-1.5310
HGW	0.3159	0.7998	0.3121	0.3084	0.4988
YIE	0.6469	0.4450	-0.3960	0.8469	-0.2894
Secondary					
SD	0.2494	0.1640	0.0154	0.5032	-0.8469
EH	-0.0423	-0.9473	0.3144	0.1657	-0.1275
PH	0.4855	-0.4774	-0.2477	0.4516	0.0001
IH	-0.3202	0.0827	-0.6069	-0.0692	-0.1954
DPW	0.4758	-0.2336	-0.1283	-0.9177	0.6123
CC	0.1261	0.2774	0.7860	-0.6317	-0.2348
PW	-0.0126	-0.2764	0.7369	0.7055	0.5568
R^2	0.799	0.680	0.381	0.307	0.162
p-value	<0.001	<0.001	0.05	0.07	0.07
DF	35	24	15	8	3

DEW: Dry ear weight, EL: Ear length, ED: Ear diameter, HGW: Hundred grain weight, YIE: Grain yield, SD: Stem diameter, EH: Ear height, PH: Plant height, IL: Inflorescence length, DPW: Dry plant weight, CC: Chlorophyll content, PW: Plant weight, R^2: Coefficient of determination, DF: Degrees of freedom

2006), sugarcane (Da Silva *et al.*, 2007), potato (Rigao *et al.*, 2009) and wheat (Erayman *et al.,* 2006; Carvalho *et al.*, 2015).

Intergroup associations were established mainly by influences from: first pair of canonical correlations combines high yield with bigger plants, second pair of canonical correlations combines ears of greater weight with lower ear insertion height and third pair canonical associated greater weight per ear with increased chlorophyll. These results indicate that the increase in Plant Height (PH) and the reduction of Ear Height (EH) are desirable associations for increasing yield plant, resembling with results obtained by Fancelli and Dourado-Neto (1999) and Teodoro *et al.* (2014). Alternatively, plants with erect leaf architecture, which optimize photosynthetic efficiency, especially at reduced spacing, also provide increased yield per plant (Batista *et al.*, 2012; Torres *et al.*, 2013).

Table 3 shows the structural matrix coefficients or canonical factors matrix, i.e., the correlation matrix between the original and canonical variables. The canonical loads (or canonical structural correlations) measure the simple linear correlation between an original variable observed in the dependent or independent set and canonical statistical variable of its respective set. The higher the load, more important is the variable to derive the canonical statistical variable (Santos *et al.*, 1994; Tavares *et al.*, 1999; Coimbra *et al.*, 2000; Neto *et al.*, 2006; Da Silva *et al.*, 2007; Rigao *et al.*, 2009; Carvalho *et al.*, 2015).

In view of the obtained results, selection of plants with higher height, stem diameter, dry weight and lower ear height will result in increase of primary production components (dry ear weight, ear length and hundred grain weight), allowing the targeting of maize breeding program.

Whereas, the fewer the number of factors, most interesting are the Factors Analysis (FA) results. Initially, the FA was made with the early definition of four factors, which did not allow the extraction of a factor whose associated eigenvalue was greater than unity. Thus, we proceeded to analysis with five and six factors as recommended by Steel *et al.* (1997) and Hair *et al.* (2006). Analysis with six factors did not improve the breakdown of results and thus, we presented only the result of the analysis of five factors (Table 4).

From the final factor loads were identified the factors: first factor relates the plant height, dry plant weight and dry ear weight and ear length, being similar to the canonical loads obtained for their first pair, which reinforces the association hypothesis between these traits; second factor brought together the traits ear height and inflorescence length, third factor had the highest factor loads for stem diameter and plant weight and fourth factor brought together the traits hundred grain weight and grain yield. These results confirm those obtained by Teodoro *et al.* (2014), who claim that the trait hundred grain weight is what most influences the maize yield. Lastly, the fifth factor brought together the traits chlorophyll and ear diameter.

Factor Analysis allows reducing a large number of original variables observed to a small number of abstract variables, where each factor brought together original variables strongly correlated, but weakly correlated with other factors (Steel *et al.*, 1997; Hair *et al.*, 2006). Knowledge of existing

Table 3: Matrix of canonical loads between the primary components from group I and secondary components from group II, assessed in the population Guepa-I, after 13 stratified mass section cycles

	Canonical loads				
Components	1°	2°	3°	4°	5°
Primary					
DEW	0.9129	-0.3478	-0.1802	-0.0020	-0.1139
EL	0.8557	-0.2150	0.4476	-0.0739	0.1247
ED	0.4607	0.0273	-0.5202	0.0259	-0.7180
HGW	0.2463	0.7281	-0.0113	0.5402	0.3421
YIE	0.2039	-0.0825	0.1670	0.9469	-0.1641
Secondary					
SD	0.5865	-0.0488	-0.2611	0.2617	-0.4317
EH	0.2730	-0.8215	-0.0040	-0.1202	-0.2801
PH	0.7119	0.2906	0.1469	0.0889	0.1911
IH	0.3141	-0.1378	0.1540	0.2219	-0.3476
DPW	0.7830	-0.1750	0.0314	-0.2234	0.3849
CC	0.2192	0.2858	-0.6264	-0.4743	-0.3680
PW	0.3032	0.0668	-0.5704	0.5035	0.3753

DEW: Dry ear weight, EL: Ear length, ED: Ear diameter, HGW: Hundred grain weight, YIE: Grain yield, SD: Stem diameter, EH: Ear height, PH: Plant height, IL: Inflorescence length, DPW: Dry plant weight, CC: Chlorophyll content, PW: Plant weight, R^2: Coefficient of determination

Table 4: Factorial loads after rotation (with 5 factors), assessed in the population Guepa-I, after 13 stratified mass section cycles

Traits	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Commonalities
SD	0.358	-0.177	0.665	-0.034	0.067	0.608
EH	0.359	-0.649	-0.352	-0.296	-0.001	0.762
PH	0.759	0.202	-0.176	0.295	0.242	0.793
IL	-0.039	-0.766	0.276	0.113	0.175	0.708
DPW	0.797	0.167	0.328	-0.118	-0.108	0.796
CC	-0.048	-0.077	0.010	0.017	0.899	0.816
PW	0.026	0.022	0.838	0.159	0.079	0.735
DEW	0.784	-0.305	0.289	-0.164	0.234	0.872
EL	0.827	-0.242	0.087	-0.007	-0.048	0.753
ED	0.262	-0.141	0.333	-0.164	0.507	0.484
HGW	0.116	0.178	0.111	0.881	0.093	0.842
YIE	-0.186	-0.306	0.020	0.761	-0.328	0.674

SD: Stem diameter (mm), EH: Ear height (cm), PH: Plant height (cm), IL: Inflorescence length (cm), DPW: Dry plant weight (g), CC: Chlorophyll content, PW: Plant weight (g), DEW: Dry ear weight (g), EL: Ear length (cm), ED: Ear diameter (mm), HGW: Hundred grain weight (g), YIE: Grain yield

biological relationship between measured traits will enable a more careful choice of variables on which it should exercise selection, because the variables grouped in each factor are those that best explain each of the referred phenomena.

CONCLUSIONS

Primary and secondary yield components of maize grains are not independent. Inter-group associations are established by plants with higher height, stem diameter, dry weight and lower ear height, which positively influence primary yield components (dry ear weight, ear length and hundred grain weight).

Factor analysis allowed to reduce a large number of original variables observed to a small number of abstract variables and can be used to complement the canonical variables technique.

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